APPENDIX D

LOW CARBON TRANSPORTATION AND FUELS INVESTMENTS AND THE AIR QUALITY IMPROVEMENT PROGRAM

Fiscal Year 2016-17
Off-Road Advanced Technology Demonstration Projects

METHODOLOGY FOR DETERMINING EMISSION REDUCTIONS AND COST-EFFECTIVENESS

Mobile Source Control Division
California Air Resources Board
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California Environmental Protection Agency

Air Resources Board

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ABBREVIATIONS

The following abbreviations are used in this appendix:

"AQIP" means the Air Quality Improvement Program.
"ATV" means advanced technology vehicle.
"bhp-hr" means brake-horsepower-hour.
"CARB" means the California Air Resources Board.
"CARBOB" means California Reformulated Gasoline Blendstock for Oxygenate Blending.
"CaRFG" means California reformulated gasoline.
"CI" means carbon intensity.
"CO2e" means carbon dioxide equivalent.
"CNG" means compressed natural gas.
"CRF" means capital recovery factor.
"ED" means fuel energy density.
"EER" means energy economy ratio.
"EF" means emission factor.
"ER" means emission reduction.
"FAME biodiesel" means fatty acid methyl esters biodiesel.
"g/bhp-hr" means grams per brake-horsepower-hour.
"gal" means gallon.
"GHG" means greenhouse gas.
"GVWR" means gross vehicle weight rating.
"HC" means hydrocarbon.
"hp" means horsepower.
"kWh" means kilowatt-hour.
"LNG" means liquefied natural gas.
"LSI" means large spark-ignition.
"MJ" means megajoule.
"NMHC" means non-methane hydrocarbon.
"NOx" means oxides of nitrogen.
"PM" means particulate matter.
"PM10" means particulate matter less than 10 microns in diameter.
"ROG" means reactive organic gases.
"scf" means standard cubic foot.
"ULSD" means ultra-low sulfur diesel.
"WER" means weighted surplus emission reduction.
"yr" means year.

I. OVERVIEW

The methodology below must be used to calculate the emission reductions and cost-effectiveness of projects proposed under this Solicitation. All calculations and assumptions made must be shown clearly and in their entirety in the application (Appendix A, Attachment 3).

All calculations will use the cleanest commercially available diesel-fueled vehicle or piece of equipment, which in many cases will employ a 2017 model year or Tier 4 Final engine, for baseline greenhouse gas (GHG) and criteria pollutant emission calculations. This technique may not adequately capture the emission profiles of all proposed applications; however to ensure all applications are scored on an objective basis, this technique will be used for scoring all submitted applications. Alternate calculation methodologies, in addition to that required above, may be submitted to illustrate the potential emission reductions from the proposed projects.

GHG emission calculations are to be based on life cycle analysis (well-to-wheel). Criteria pollutant and PM emission calculations are to be based on exhaust emissions (tank-to-wheel). The GHG emission factors in Section II, below, are excerpted from the 2015 Low Carbon Fuel Standard (LCFS) regulation.[1] Please note that while the LCFS fuel carbon intensity values may change during the Solicitation period, project applicants must use the values listed in this appendix. The remaining emission factors and methodology below are from Appendices C, D, and G of the California Air Resources Board (CARB or Board) approved 2011 Carl Moyer Program Guidelines (Moyer Guidelines), as updated in 2016.[2] Language has been modified where necessary for the purposes of this Solicitation. The complete Moyer Guidelines, including all of its appendices, can be found at http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm.

Emission factors for engines that meet an optional low oxides-of-nitrogen (NOx) standard are given for the purpose of this Solicitation only and are based on emission factors developed for the FY 2016-17 Air Quality Improvement Program (AQIP) and Low Carbon Transportation (LCT) Investments Funding Plan.

If a proposed project is for an application that uses a baseline diesel engine of 24 horsepower (hp) or lower, for the purpose of this solicitation and to calculate the needed emission reductions and cost-effectiveness, use the relevant tables for a 25 hp baseline diesel engine in the Moyer Guidelines.

Please see the example calculations provided in Section V of this Appendix to better understand how the following formulas and figures used to calculate emission reduction and cost-effectiveness values. Any examples provided herein are for reference only

[1] CARB, 2015; Low Carbon Fuel Standard, https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.
[2] CARB, 2016; The 2011 Carl Moyer Program Guidelines, https://www.arb.ca.gov/msprog/moyer/guidelines/2011gl/2011cmpgl_20161228.pdf

and do not imply additional demonstration project types or categories, nor do Carl Moyer Program funding amounts limit the amount of funding that may be available for demonstration projects. Criteria pollutant and particulate matter (PM) table numbers are the same as those in the 2017 Moyer Guidelines. While Carl Moyer Program guidelines may change during the Solicitation period, project applicants must use the values listed in this appendix.

II. EMISSION FACTORS FOR GHG

The following emission factors apply when calculating emission reductions and cost-effectiveness and are applied to Off-Road Advanced Technology Demonstration Projects:

Table II-1: Fuel Energy Density[3]

Fuel (units)	*Energy Density*
CARBOB (gal)	119.53 (MJ/gal)
CaRFG (gal)	115.83 (MJ/gal)
Diesel fuel (gal)	134.47 (MJ/gal)
CNG (scf)	1.04 (MJ/scf)
LNG (gal)	78.83 (MJ/gal)
Electricity (KWh)	3.60 (MJ/KWh)
Hydrogen (kg)	120.00 (MJ/kg)
Denatured Ethanol (gal)	81.51 (MJ/gal)
FAME Biodiesel (gal)	126.13 (MJ/gal)
Renewable Diesel (gal)	129.65 (MJ/gal)

Table II-2: Fuel Carbon Intensity Values[4,5]

Fuel	Pathway Identifier	Carbon Intensity Values (gCO_2e/MJ)
ULSD – based on the average crude oil supplied to California refineries and average California refinery efficiencies	ULSD001	102.01
CaRFG (calculated)	--	98.47
Fossil CNG	CNG400T	78.37
Fossil LNG	LNG401T	94.42
Biomethane CNG	CNG500T	46.42
Biomethane LNG	LNG501T	64.63
Biodiesel – any feedstock	BIOD202T	102.01
Renewable Diesel – any feedstock	RNWD302T	102.01
Ethanol – corn	ETH100T	75.97
Ethanol – any starch or sugar feedstock	ETH103T	98.47
Hydrogen – all sources	HYGN005	88.33
Electricity – California average	ELC001	105.16

[3] CARB, 2015; LCFS Regulation, Table 3: Energy Densities of LCFS Fuels and Blendstocks. https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf

[4] CARB, 2016; LCFS Temporary Pathway Table. https://www.arb.ca.gov/fuels/lcfs/fuelpathways/temporarypathwaytable.htm, accessed [June 8, 2017].

[5] CARB, 2015; LCFS Regulation. https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf

Table II-3: EER Values for Fuels Used in Light-, Medium-, and Heavy-Duty Applications[6]

Fuels Used as a Diesel Replacement for Heavy-Duty and Off-Road Applications	
Fuel/Vehicle Combinations	**EER Value Relative to Diesel**
Diesel Fuel or Biomass Based Diesel Blends	1.0
CNG or LNG/Any Vehicles (Spark-Ignition Engines)	0.9
CNG/LNG /Any Vehicle (Compression-Ignition Engines)	1.0
Electricity / Battery Electric or Plug-in Hybrid Electric Truck	2.7
Electricity / Battery Electric or Plug-in Hybrid Electric Bus	4.2
Electricity / Fixed Guideway, Heavy Rail	4.6
Electricity / Fixed Guideway, Light Rail	3.3
Electricity / Trolley Bus, Cable Car, Street Car	3.1
Electricity/Forklifts or Equipment	3.8
H_2 / Fuel Cell Vehicle	1.9
H_2 / Fuel Cell Forklifts	2.1

Table II-4: Low NOx Engine Emission Values[7]

Low NOx Engine Emission Factors g/gallon diesel consumed			
Low NOx Standard g/bhp-hr	**NOx g/gal**	**ROG g/gal**	**PM g/gal**
0.1	1.7	0.18	0.148
0.05	0.85	0.18	0.148
0.02	0.344	0.18	0.148

Note that Low NOx emission factors have only been established for 0.02 g/bhp-hr as described in the FY 2016-17 AQIP and LCT Investments Funding Plan. NOx emission factors for 0.1 g/bhp-hr and 0.05 g/bhp-hr are extrapolated and only intended for use in applying for funding under this solicitation. Also note that no emission benefit is assumed for reactive organic gases (ROG) and PM from the use of a Low NOx engine.

[6] CARB, 2015; Low Carbon Fuel Standard, Table 4: EER Values for Fuels Used in Light- and Medium-Duty, and Heavy-Duty Applications; https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf
[7] CARB, 2016; Proposed Fiscal Year 2016-17 Funding Plan For Low Carbon Transportation and Fuels Investments and the Air Quality Improvement Program; https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_fy16-17_fundingplan_full.pdf

III. GHG EMISSIONS CALCULATIONS[8]: COST-EFFECTIVENESS AND EMISSION REDUCTION FORMULAS

A. Well-to-Wheel GHG Emission Calculations

Formula 1 and Formula 2 are used to calculate the GHG emission factor in grams of carbon dioxide equivalent (CO2e) per year of use. Formula 2 is used to determine the fuel usage of the baseline vehicle or equipment.

Formula 1 calculates the greenhouse gas emission factor (GHG EF) using the carbon intensity (CI) of the fuel, the fuel's energy density, and the annual fuel usage for the technology employed in the vehicle/equipment.

Formula 1: Greenhouse Gas Emission Factor Based on Fuel Usage

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right) * \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

Where CI is provided in Table II-2 and fuel energy density is provided in Table II-1.

Formula 2: Annual Fuel Usage

Formula 2 should be used to determine the fuel usage for the baseline vehicle or equipment based on hours of operations and/or miles driven and the fuel economy of the baseline vehicle or equipment.

$$Fuel\ Usage\ \left(\frac{gal}{year}\right) = \left(\frac{gal}{mile}\ or\ \frac{gal}{hour}\right) * \left(\frac{miles}{day}\ or\ \frac{hours}{day}\right) * \left(\frac{days}{year}\right)$$

B. Conversion from Diesel Fuel Usage to Electricity / Hydrogen / CNG Usage

Formula 3 is used to calculate the advanced technology vehicle (ATV) fuel usage based on the diesel usage of the baseline vehicle/equipment calculated from Formula 2.

[8] GHG emissions are measured in "CO_2 equivalent", which means the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas.

Formula 3:

$$ATV\ Fuel\ Usage\left(\frac{unit}{year}\right) = Baseline\ fuel\ usage * ED_{diesel} * \left(\frac{1}{ED_{replacement\ fuel}}\right) * \left(\frac{1}{EER}\right)$$

Where:

- **ED** is the fuel energy density (see Table II-1: Fuel Energy Density);
- **EER** is the Energy Economy Ratio value for fuels relative to diesel (see Table D-3: EER Values for Fuels Used in Light-, Medium-, and Heavy-Duty Applications); and
- **Unit** is the units associated with the replacement fuel. Electricity usage is in units of kWh, hydrogen is in kg, and CNG is in standard cubic feet (scf).

C. GHG Emission Reduction Calculation

The project's GHG emission reduction value is determined by taking the difference between the GHG emissions of the baseline vehicle or equipment and the advanced technology vehicle or equipment.

Baseline vehicles or equipment are those using the cleanest engines commercially available at the time the application for funding is submitted, which for the purposes of this solicitation is a Tier 4 Final engine, or the cleanest 2017 model year engine if a Tier 4 Final engine is not commercially available.

Formula 4 is used to determine the annual GHG emission reductions (GHG ER_{annual}) associated with the ATV.

Formula 4:

$$Project\ GHG\ ER_{annual}\left(\frac{metric\ tons\ CO2e}{year}\right) = GHG\ EF_{base} - GHG\ EF_{ATV}$$

Where:

- **Project GHG ER_{annual}** is the annual GHG emission reductions that are associated with the proposed project;
- **GHG EF_{base}** is the GHG emission factor associated with the baseline vehicle or equipment that the advanced technology vehicle or equipment is compared against; and
- **GHG ER_{ATV}** is the GHG emission factor that is associated with the proposed advanced technology vehicle.

D. Cost-Effectiveness Calculations for GHG

The cost-effectiveness of a project is determined by dividing the annualized cost of the potential project by the annual emission reductions that will be achieved by the project as shown in Formula 5 below.

Formula 5 is used to determine the cost-effectiveness of the project in dollars per ton of emissions reduced.

Formula 5:

$$Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton\ CO2e}\right) = \frac{CRF * incremental\ cost}{Project\ GHG\ ER_{annual}}$$

Where, for the purposes of this Solicitation:

- **CRF** is the Capital Recovery Factor;
- **CRF_2 = 0.515** (2-year life) [9];
- **CRF_{10} = 0.111** (10-year life)[10]; and
- **Incremental cost** is the difference between the cost of the baseline vehicle or equipment and the advanced technology vehicle or equipment.

E. Composite Carbon Intensity Calculations

Formula 6 below is used to determine a composite carbon intensity value in the calculations if two of the same fuel types are to be blended for use in the proposed vehicle or equipment. Use values from Table II-2: Fuel Carbon Intensity Values above as inputs into Formula 6.

Formula 6:

$$CI_{composite} = (fraction\ of\ total\ fuel * CI_{fuel\ 1}) + (fraction\ of\ total\ fuel * CI_{fuel\ 2})$$

F. Advanced Technology Efficiency Calculation

Formula 7 should be used to determine the amount of fuel per year necessary to operate an advanced technology vehicle or equipment that provides a percent efficiency improvement. Use results from Formula 2 to determine the annual fuel usage for the baseline vehicle or equipment.

Formula 7:

$$Fuel\ Usage_{ATV}\left(\frac{gal}{year}\right) = \ fuel\ usage * \left(1 - \frac{(X * Y\%\ improvement)}{100\%}\right)$$

Where:

[9] CARB, 2016; The 2011 Carl Moyer Program Guidelines Appendix G: Table G-3a. https://www.arb.ca.gov/msprog/moyer/guidelines/2011gl/2011cmp_appg_20151218.pdf

- **X** is the fraction of the time the advanced operational efficiency technology or logistic strategy is enabled and providing emission reductions. If the advanced operational efficiency technology or logistic strategy is always engaged and providing emission reductions assume that X is equal to 1; and
- **Y** is the percentage fuel economy improvement that is gained by having the advanced operational efficiency technology or logistic strategy efficiency improvement over the baseline engine.

IV. CRITERIA POLLUTANT AND PARTICULATE MATTER EMISSIONS CALCULATIONS: COST-EFFECTIVENESS AND EMISSION REDUCTION

Formulas are taken from Appendix C of the 2011 Moyer Guidelines. Other sections of the Moyer Guidelines are referenced as well. Language has been modified where necessary for the purposes of this Solicitation. Tables that contain emission factors and necessary inputs follow at the end of this section. Updates to these tables in the Moyer Guidelines may have been made since the release of this Solicitation. Only use the information included in the tables in this Solicitation for criteria pollutant reduction and cost-effectiveness calculations.

Baseline vehicles or equipment for the purpose of this Solicitation are the cleanest vehicle or equipment commercially available at the time the application for funding is submitted.

A. Calculating Cost-Effectiveness

The cost-effectiveness of a potential project is determined by dividing the annualized cost of the project by the annual weighted surplus emission reductions that will be achieved by the project as shown in Formula 8 below.

Formula 8: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year)}}{\textit{Annual Weighted Surplus Emission Reductions (tons/year)}}$$

Where Annualized Cost is calculated using Formula 9 and Annual Weighted Surplus Emission Reductions is calculated using Formula 11.

Descriptions on how to calculate annual emission reductions and annualized cost are provided in the following sections.

B. Determining the Annualized Cost

Annualized cost is the amortization of the one-time incentive grant amount for the life of the project to yield an estimated annual cost. The annualized cost is calculated by multiplying the incremental cost by the capital recovery factor (CRF). [NOTE: For the purposes of this calculation, the CRF is 0.111, which assumes a 10-year life.] The resulting annualized cost is used to complete Formula 8 above to determine the cost-effectiveness of surplus emission reductions.

Formula 9: Annualized Cost ($)

*Annualized Cost = CRF * incremental cost ($)*

Where: **CRF_2 = 0.515**, (2 year life)[10];
CRF_{10} = 0.111, (10-year life)[11]; and
Incremental cost is calculated using Formula 10.

C. Calculating the Incremental Cost

Formula 10: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Technology ($)

D. Calculating the Annual Weighted Surplus Emission Reductions

Annual weighted surplus emission reductions (WER) are estimated by taking the sum of the project's annual surplus pollutant reductions following Formula 11 below. This will allow projects that reduce one, two, or all three of the covered pollutants to be evaluated. While NOx and ROG emissions are given equal weight, emissions of PM carry a greater weight in the calculation.

Formula 11: Annual Weighted Surplus Emission Reductions (tons/yr)

Annual Weighted Surplus Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

The result of Formula 11 is used to complete Formula 8 to determine the cost-effectiveness of surplus emission reductions.

In order to determine the annual surplus emission reductions by pollutant, emission reduction calculations need to be completed for each pollutant (NOx, ROG, and PM), for the baseline technology and the advanced technology, totaling up to six calculations:

[10] CARB, 2016; The 2011 Carl Moyer Program Guidelines Appendix G: Table G-3a. https://www.arb.ca.gov/msprog/moyer/guidelines/2011gl/2011cmp_appg_20151218.pdf

Baseline Technology	Advanced Technology
1. Annual emissions of NOx	4. Annual emissions of NOx
2. Annual emissions of ROG	5. Annual emissions of ROG
3. Annual emissions of PM	6. Annual emissions of PM

These calculations are completed for each pollutant by multiplying the engine emission factor or converted emission standard by the annual activity level of the technology and by other adjustment factors as specified for the calculation methodologies presented.

E. Calculating Annual Emission Reductions based on Usage

1. Calculating Annual Emission Reductions Based on Hours of Operation

When actual annual hours of equipment operation are the basis for determining emission reductions, use Formula 12 below.

Formula 12: Estimated Annual Emission Reductions Based on Hours of Operation (tons/year)

Annual Emission Reductions =

> *Emission Factor or Converted Emission Standard (g/bhp-hr) * Horsepower * Load Factor * Activity (hrs/yr) * Percent Operation in California * ton/907,200g*
>
> Where the Emission Factor is provided in Table IV-3, IV-4, IV-6, IV-7, IV-9, IV-10, IV-11, IV-12a, IV-12b, IV-14a, IV-14b, IV-15a, or IV-15b; the Converted Emission Standard is provided in Table IV-1 or IV-2; and the Load Factor is provided in Table IV-5, IV-8, or IV-16.

2. Calculating Annual Emissions Based on Fuel Consumption

When annual fuel consumption is used for determining emission reductions, the equipment activity level must be based on annual fuel usage within California provided by the applicant.

A fuel consumption rate factor must be used to convert emissions given in g/bhp-hr to units of grams of emissions per gallon of fuel used (g/gal). The fuel consumption rate factor is a number that combines the effects of engine efficiency and the energy content of the fuel used in that engine into an approximation of the amount of work output by an engine for each unit of fuel consumed. Formulas 13 and 14 below are the formulas for calculating annual emissions based on annual fuel consumed.

Formula 13: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Where the fuel consumption rate factor is provided in Table IV-19.

Formula 14: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr)

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

F. List of Criteria Pollutant Cost-Effectiveness Formulas

For an easy reference, the necessary formulas to calculate the cost-effectiveness of surplus emission reductions for a project funded through the Carl Moyer Program are provided below.

Formula 8: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton):

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year)}}{\textit{Annual Weighted Surplus Emission Reductions (tons/yr)}}$$

Formula 9: Annualized Cost ($)

*Annualized Cost = CRF * incremental cost ($)*

Formula 10: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Technology ($)

Formula 11: Annual Weighted Surplus Emission Reductions

Annual Weighted Surplus Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

Formula 12: Estimated Annual Emission Reductions Based on Hours of Operation (tons/year)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * Horsepower * Load Factor * Activity (hrs/yr) * Percent Operation in California * ton/907,200g*

Formula 13: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Formula 14: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr)

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

G. Tables for Calculating Criteria and Toxic Pollutant Emission Reductions

ON-ROAD TRUCK TABLES

Table IV-1
Diesel Heavy-Duty Engines
Converted Emission Standards for Fuel Based Usage Calculations

EO Certification Standards g/bhp-hr		NOx	ROG[(a)]	PM10
		g/gal[(b)(c)(d)]		
6.0 NOx	0.60 PM10	103.23	5.33	7.992
5.0 NOx	0.25 PM10	86.03	4.44	3.330
5.0 NOx	0.10 PM10	86.03	4.44	1.332
4.0 NOx	0.10 PM10	68.82	3.55	1.332
2.5 NOx + NMHC	0.10 PM10	40.86	2.11	1.332
1.8 NOx + NMHC	0.01 PM10	29.42	1.52	0.148
1.5 NOx + NMHC	0.01 PM10	24.52	1.27	0.148
1.2 NOx + NMHC	0.01 PM10	19.61	1.01	0.148
0.84 NOx + NMHC	0.01 PM10	13.73	0.71	0.148
0.50 NOx	0.01 PM10	8.60	0.44	0.148
0.20 NOX	0.01 PM10	3.44	0.18	0.148

Table IV-2
Alternative Fuel Heavy-Duty Engines
Converted Emission Standards for Fuel Based Usage Calculations

EO Certification Standards g/bhp-hr		NOx	ROG[(a)]	PM10
		g/gal[(b)(c)(d)]		
6.0 NOx	0.60 PM10	111.00	35.14	11.100
5.0 NOx	0.25 PM10	92.50	29.29	4.625
5.0 NOx	0.10 PM10	92.50	29.29	1.850
4.0 NOx	0.10 PM10	74.00	23.43	1.850
2.5 NOx + NMHC	0.10 PM10	37.00	11.71	1.850
1.8 NOx + NMHC	0.01 PM10	26.64	8.43	0.185
1.5 NOx + NMHC	0.01 PM10	22.20	7.03	0.185
1.2 NOx + NMHC	0.01 PM10	17.76	5.62	0.185
0.84 NOx + NMHC	0.01 PM10	12.43	3.94	0.185
0.50 NOx	0.01 PM10	9.25	2.93	0.185
0.20 NOX	0.01 PM10	3.70	1.17	0.185

a - ROG = HC * 1.26639.
b - Fuel based emissions factors were calculated using fuel consumption rate factors from Table IV-19.
c - Fuel based factors are for engines less than 750 horsepower only.
d - Emission standards were converted where appropriate, using the NMHC and NOx fraction default values and the ultra low sulfur diesel fuel correction factors listed in Table D-25 and D-26 of the Moyer Guidelines, respectively.

Table IV-3
Heavy-Duty Vehicles
14,001-33,000 pounds (lbs) Gross Vehicle Weight Rating (GVWR)
Emission Factors for Mileage Based Calculations (g/mile)a

Model Year	Diesel[(b)]		
	NOx	ROG[(c)]	PM10
Pre-1987	14.52	0.75	0.695
1987-1990	14.31	0.59	0.755
1991-1993	10.70	0.26	0.409
1994-1997	10.51	0.20	0.226
1998-2002	10.33	0.20	0.249
2003-2006	6.84	0.13	0.157
2007-2009	4.01	0.11	0.017
2007+ (0.21-0.50 g/bhp-hr NOx)[(d)]	1.73	0.10	0.017
2010+ (0.20 g/bhp-hr NOx or cleaner)	0.74	0.09	0.017

Table IV-4
Heavy-Duty Vehicles
Over 33,000 lbs GVWR
Emission Factors for Mileage Based Calculations (g/mile)[a]

Model Year	Diesel[(b)]		
	NOx	ROG[(c)]	PM10
Pre-1987	21.37	1.09	1.247
1987-1990	21.07	0.86	1.355
1991-1993	18.24	0.56	0.562
1994-1997	17.92	0.42	0.365
1998-2002	17.61	0.43	0.403
2003-2006	11.64	0.27	0.254
2007-2009	6.62	0.23	0.028
2007+ (0.21-0.50 g/bhp-hr NOx)[(d)]	2.88	0.20	0.028
2010+ (0.20 g/bhp-hr NOx or cleaner)	1.27	0.19	0.028

a - EMFAC 2011 Zero-Mile Based Emission Factors.
b - Emission factors reflect the ultra low sulfur diesel fuel correction factors listed in Table D-26 of the Moyer Guidelines.
c - ROG = HC * 1.26639.
d - Use interpolated values assuming 1.2 g/bhp-hr NOx Standards for 2007-2009 Model Year Grouping and 0.2 g/bhp-hr NOx Standards for 2010+ Model Years.

OFF-ROAD PROJECTS AND NON-MOBILE AGRICULTURAL PROJECTS

Table IV-5
Off-Road Diesel Engines Default Load Factors

Category	Equipment Type	Load Factor
Airport Ground Support	Aircraft Tug	0.54
	Air Conditioner	0.75
	Air Start Unit	0.90
	Baggage Tug	0.37
	Belt Loader	0.34
	Bobtail	0.37
	Cargo Loader	0.34
	Cargo Tractor	0.36
	Forklift	0.20
	Ground Power Unit	0.75
	Lift	0.34
	Passenger Stand	0.40
	Service Truck	0.20
	Other GSE	0.34
Agricultural (Mobile, Portable or Stationary)	Agricultural Mowers	0.43
	Agricultural Tractors	0.70
	Balers	0.58
	Combines/Choppers	0.70
	Chippers/Stump Grinders	0.73
	Generator Sets	0.74
	Hydro Power Units	0.48
	Irrigation Pump	0.65
	Shredders	0.40
	Sprayers	0.50
	Swathers	0.55
	Tillers	0.78
	Other Agricultural	0.51
Construction	Air Compressors	0.48
	Bore/Drill Rigs	0.50
	Cement & Mortar Mixers	0.56
	Concrete/Industrial Saws	0.73
	Concrete/Trash Pump	0.74
	Cranes	0.29
	Crawler Tractors	0.43
	Crushing/Process Equipment	0.78
	Excavators	0.38
	Graders	0.41

Table IV-5 (Continued)

Off-Road Diesel Engines Default Load FactorsCategory	Equipment Type	Load Factor
Construction	Off-Highway Tractors	0.44
	Off-Highway Trucks	0.38
	Pavers	0.42
	Other Paving	0.36
	Pressure Washer	0.30
	Rollers	0.38
	Rough Terrain Forklifts	0.40
	Rubber Tired Dozers	0.40
	Rubber Tired Loaders	0.36
	Scrapers	0.48
	Signal Boards	0.78
	Skid Steer Loaders	0.37
	Surfacing Equipment	0.30
	Tractors/Loaders/Backhoes	0.37
	Trenchers	0.50
	Welders	0.45
	Other Construction Equipment	0.42
Industrial	Aerial Lifts	0.31
	Forklifts	0.20
	Sweepers/Scrubbers	0.46
	Other General Industrial	0.34
	Other Material Handling	0.40
Logging	Fellers/Bunchers	0.71
	Skidders	0.74
Oil Drilling	Drill Rig	0.50
	Lift (Drilling)	0.60
	Swivel	0.60
	Workover Rig (Mobile)	0.50
	Other Workover Equipment	0.60
Cargo Handling	Container Handling Equipment	0.59
	Cranes	0.43
	Excavators	0.57
	Forklifts	0.30
	Other Cargo Handling Equipment	0.51
	Sweeper/Scrubber	0.68
	Tractors/Loaders/Backhoes	0.55
	Yard Trucks	0.65
Other	All	0.43

Table IV-6
Uncontrolled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)

Horsepower	Model Year	NOx	ROG	PM10
25 – 49	pre-1988	6.51	2.21	0.547
	1988 +	6.42	2.17	0.547
50 – 119	pre-1988	12.09	1.73	0.605
	1988 +	8.14	1.19	0.497
120+	pre-1970	13.02	1.59	0.554
	1970 – 1979	11.16	1.20	0.396
	1980 – 1987	10.23	1.06	0.396
	1988 +	7.60	0.82	0.274

Table IV-7
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)[a]

Horsepower	Tier	NOx	ROG	PM10
25-49	1	5.26	1.74	0.480
	2	4.63	0.29	0.280
	4 Interim	4.55	0.12	0.128
	4 Final	2.75	0.12	0.008
50-74	1	6.54	1.19	0.552
	2	4.75	0.23	0.192
	3[(b)]	2.74	0.12	0.192
	4 Interim	2.74	0.12	0.112
	4 Final	2.74	0.12	0.008
75-99	1	6.54	1.19	0.552
	2	4.75	0.23	0.192
	3	2.74	0.12	0.192
	4 Phase-Out	2.74	0.12	0.008
	4 Phase-In/ Alternate NOx	2.14	0.11	0.008
	4 Final	0.26	0.06	0.008
100-174	1	6.54	0.82	0.274
	2	4.17	0.19	0.128
	3	2.32	0.12	0.112
	4 Phase-Out	2.32	0.12	0.008
	4 Phase-In/ Alternate NOx	2.15	0.06	0.008
	4 Final	0.26	0.06	0.008
175-299	1	5.93	0.38	0.108
	2	4.15	0.12	0.088
	3	2.32	0.12	0.088
	4 Phase-Out	2.32	0.12	0.008
	4 Phase-In/ Alternate NOx	1.29	0.08	0.008
	4 Final	0.26	0.06	0.008

Table IV-7 (Continued)
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)a

Horsepower	Tier	NOx	ROG	PM10
300-750	1	5.93	0.38	0.108
	2	3.79	0.12	0.088
	3	2.32	0.12	0.088
	4 Phase-Out	2.32	0.12	0.008
	4 Phase-In/ Alternate NOx	1.29	0.08	0.008
	4 Final	0.26	0.06	0.008
751+	1	5.93	0.38	0.108
	2	3.79	0.12	0.088
	4 Interim	2.24	0.12	0.048
	4 Final	2.24	0.06	0.016

Note: Engines that are participating in the "Tier 4 Early Introduction Incentive for Engine Manufacturers" program per California Code of Regulations, Title 13, section 2423(b)(6) are eligible for funding provided the engines are certified to the final Tier 4 emission standards. The CARB Executive Order indicates engines certified under this provision. The emission rates for these engines used to determine cost-effectiveness shall be equivalent to the emission factors associated with Tier 3 engines.

For equipment with baseline engines certified under the flexibility provisions per California Code of Regulations, Title 13, section 2423(d), baseline emission rates shall be determined by using the previous applicable emission standard or Tier for that engine model year and horsepower rating. The CARB Executive Order indicates engines certified under this provision.

a - Emission factors were converted using the ultra low sulfur diesel fuel correction factors listed in Table D-27 of the Moyer Guidelines.
b - Alternate compliance option.

LARGE SPARK IGNITION ENGINES (LSI)

Table IV-8
Off-Road LSI Equipment Default Load Factors

Category	Equipment Type	Load Factor
Agriculture (Mobile, Portable or Stationary)	Agricultural Tractors	0.62
	Balers	0.55
	Combines/Choppers	0.74
	Chipper/Stump Grinder	0.78
	Generator Sets	0.68
	Sprayers	0.50
	Swathers	0.52
	Pumps	0.65
	Other Agricultural Equipment	0.55
Airport Ground Support	A/C Tug	0.80
	Baggage Tug	0.55
	Belt Loader	0.50
	Bobtail	0.55
	Cargo Loader	0.50
	Forklift	0.30
	Ground Power Unit	0.75
	Lift	0.50
	Passenger Stand	0.59
	Other GSE	0.50
Construction	Air Compressors	0.56
	Asphalt Pavers	0.66
	Bore/Drill Rigs	0.79
	Concrete/Industrial Saws	0.78
	Concrete/Trash Pump	0.69
	Cranes	0.47
	Gas Compressor	0.85
	Paving Equipment	0.59
	Pressure Washer	0.85
	Rollers	0.62
	Rough Terrain Forklifts	0.63
	Rubber Tired Loaders	0.54
	Skid Steer Loaders	0.58
	Tractors/Loaders/Backhoes	0.48

Table IV-8 (Continued)
Off-Road LSI Equipment Default Load Factors

Category	Equipment Type	Load Factor
Construction	Trenchers	0.66
	Welders	0.51
	Other Construction	0.48
Industrial	Aerial Lifts	0.46
	Forklifts	0.30
	Sweepers/Scrubbers	0.71
	Other Industrial	0.54

Table IV-9
Off-Road LSI Engines
Emission Factors (g/bhp-hr)

Horsepower	Fuel	Model Year	NOx	ROG	PM10
25 – 49	Gasoline	Uncontrolled – pre-2004	8.01	3.81	0.060
		Controlled 2001-2006	1.33	0.72	0.060
		Controlled 2007-2009[a]	0.89	0.48	0.060
		Controlled 2010+	0.27	0.14	0.060
	Alt Fuel	Uncontrolled – pre-2004	13.00	0.90	0.060
		Controlled 2001-2006	1.95	0.09	0.060
		Controlled 2007-2009[a]	1.30	0.06	0.060
		Controlled 2010+	0.39	0.02	0.060
50 – 120	Gasoline	Uncontrolled – pre-2004	11.84	2.66	0.060
		Controlled 2001-2006	1.78	0.26	0.060
		Controlled 2007-2009[a]	1.19	0.18	0.060
		Controlled 2010+	0.36	0.05	0.060
	Alt Fuel	Uncontrolled – pre-2004	10.51	1.02	0.060
		Controlled 2001-2006	1.58	0.11	0.060
		Controlled 2007-2009[a]	1.05	0.07	0.060
		Controlled 2010+	0.32	0.02	0.060
>120	Gasoline	Uncontrolled – pre-2004	12.94	1.63	0.060
		Controlled 2001-2006	1.94	0.16	0.060
		Controlled 2007-2009[a]	1.29	0.11	0.060
		Controlled 2010+	0.39	0.03	0.060
	Alt Fuel	Uncontrolled – pre-2004	10.51	0.90	0.060
		Controlled 2001-2006	1.58	0.09	0.060
		Controlled 2007-2009[a]	1.05	0.06	0.060
		Controlled 2010+	0.32	0.02	0.060

a - Emission factors for federally certified engines used in preempt equipment.

Table IV-10
Emission Factors for Off-Road LSI Engine Retrofits
Verified to Absolute Emission Number (g/bhp-hr)

Manufacturers of LSI retrofit systems may verify to a percent emission reduction or absolute emissions. If a retrofit system is verified to a percent reduction, the emission factors will be that verified percent of the appropriate emissions factors in Table IV-9. If a retrofit system is verified to an absolute emission number, use the following table for the emission factors.

Fuel	Verified Value	NOx	ROG	PM10
Gasoline	3.0 g/bhp-hr	1.78	0.26	0.060
	2.5 g/bhp-hr	1.48	0.22	0.060
	2.0 g/bhp-hr	1.19	0.18	0.060
	1.5 g/bhp-hr	0.89	0.13	0.060
	1.0 g/bhp-hr	0.59	0.09	0.060
	0.6 g/bhp-hr	0.36	0.05	0.060
	0.5 g/bhp-hr	0.30	0.04	0.060
Alt Fuel	3.0 g/bhp-hr	1.58	0.10	0.060
	2.5 g/bhp-hr	1.32	0.09	0.060
	2.0 g/bhp-hr	1.05	0.07	0.060
	1.5 g/bhp-hr	0.79	0.05	0.060
	1.0 g/bhp-hr	0.53	0.03	0.060
	0.6 g/bhp-hr	0.32	0.02	0.060
	0.5 g/bhp-hr	0.26	0.02	0.060

Table IV-11
Off-Road LSI Engines Certified to Optional Standards
Emission Factors (g/bhp-hr)

Horsepower	Fuel	Optional Standard	NOx	ROG	PM10
25-50	Gasoline	1.50	0.67	0.36	0.060
		1.00	0.44	0.24	0.060
		0.60	0.27	0.14	0.060
		0.40	0.18	0.10	0.060
		0.20	0.09	0.05	0.060
		0.10	0.04	0.02	0.060
	Alt Fuel	1.50	0.98	0.05	0.060
		1.00	0.65	0.03	0.060
		0.60	0.39	0.02	0.060
		0.40	0.26	0.01	0.060
		0.20	0.13	0.01	0.060
		0.10	0.07	0.00	0.060
50-120	Gasoline	1.50	0.89	0.13	0.060
		1.00	0.59	0.09	0.060
		0.60	0.36	0.05	0.060
		0.40	0.24	0.04	0.060
		0.20	0.12	0.02	0.060
		0.10	0.06	0.01	0.060
	Alt Fuel	1.50	0.79	0.05	0.060
		1.00	0.53	0.03	0.060
		0.60	0.32	0.02	0.060
		0.40	0.21	0.01	0.060
		0.20	0.11	0.01	0.060
		0.10	0.05	0.00	0.060
>120	Gasoline	1.50	0.97	0.08	0.060
		1.00	0.65	0.05	0.060
		0.60	0.39	0.03	0.060
		0.40	0.26	0.02	0.060
		0.20	0.13	0.01	0.060
		0.10	0.06	0.01	0.060
	Alt Fuel	1.50	0.79	0.05	0.060
		1.00	0.53	0.03	0.060
		0.60	0.32	0.02	0.060
		0.40	0.21	0.01	0.060
		0.20	0.11	0.01	0.060
		0.10	0.05	0.00	0.060

LOCOMOTIVES

Table IV-12a
Locomotive Emission Factors (g/bhp-hr)
Based on 1998 Federal Standards

Engine Model Year	Type	NOx[(a)]	ROG[(b)]	PM10[(a)]
Pre-1973	Line-haul and Passenger	12.22	0.51	0.275
	Switcher	16.36	1.06	0.378
1973-2001 Tier 0	Line-haul and Passenger	8.93	1.05	0.516
	Switcher	13.16	2.21	0.619
2002-2004 Tier 1	Line-haul and Passenger	6.96	0.58	0.387
	Switcher	10.34	1.26	0.464
2005-2011 Tier 2	Line-haul and Passenger	5.17	0.32	0.172
	Switcher	7.61	0.63	0.206

These factors are to be used for the project baseline emissions if the baseline locomotive is certified or required to be certified to the 1998 federal locomotive remanufacture standards and for the reduced emission locomotive if the project locomotive is remanufactured to these 1998 standards. Factors are based upon Regulatory Impact Analysis: Final United States Environmental Protection Agency (U.S. EPA) Locomotive Regulation (2008).
a - NOx and PM10 emission factors have been adjusted by a factor of 0.94 and 0.86, respectively, to account for use of California ultra-low sulfur diesel fuel.
b - ROG = HC * 1.053

Table IV-12b
Locomotive Emission Factors (g/bhp-hr)
Based on 2008 Federal Standards

Engine Model Year	Type	NOx[(a)]	ROG[(b)]	PM10[(a)]
1973-2001 Tier 0+	Line-haul and Passenger	6.96	0.58	0.189
	Switcher	11.09	2.21	0.224
2002-2004 Tier 1+	Line-haul and Passenger	6.96	0.58	0.189
	Switcher	10.34	1.26	0.224
2005-2011 Tier 2+	Line-haul and Passenger	5.17	0.32	0.086
	Switcher	7.61	0.63	0.112
2011-2014 Tier 3	Line-haul and Passenger	5.17	0.32	0.086
	Switcher	4.70	0.63	0.086
2015 Tier 4	Line-haul and Passenger	1.22	0.15	0.026
	Switcher	1.22	0.15	0.026

These factors are to be used for the project baseline emissions if the baseline locomotive is certified or required to be certified to the new (2008) federal locomotive remanufacture standards, and for the reduced emission locomotive if the project locomotive is remanufactured to the new standards or meets Tier 3 standards. Factors are based upon Regulatory Impact Analysis: Final U.S. EPA Locomotive Regulation (2008).
a - NOx and PM10 emission factors have been adjusted by a factor of 0.94 and 0.86, respectively, to account for use of California ultra-low sulfur diesel fuel.
b - ROG = HC * 1.053

Table IV-13
Locomotive Idle-Limiting Device Emission Reduction Factors

Type	Factor
Switchers	0.90
Line-Haul	0.97
Passenger	0.97

Note: Factors based on assumption Idle Limiting Device (ILD) reduces locomotive engine idling by 50 percent. Multiply total baseline emissions by this factor to determine reduced emissions with ILD.

MARINE VESSELS

Table IV-14a
Uncontrolled Harbor Craft Propulsion Engine
Emission Factors (g/bhp-hr)

Horsepower	Model Year	NOx	ROG	PM10
25-50	All	7.57	1.32	0.520
51-120	pre-1997	14.27	1.04	0.575
	1997+	9.70	0.71	0.524
121-250	pre-1971	15.36	0.95	0.527
	1971-1978	14.27	0.79	0.451
	1979-1983	13.17	0.72	0.376
	1984+	12.07	0.68	0.376
251+	pre-1971	15.36	0.91	0.506
	1971-1978	14.27	0.76	0.431
	1979-1983	13.17	0.68	0.363
	1984-1994	12.07	0.65	0.363
251-750	1995+	8.97	0.49	0.260
751+	1995+	12.07	0.60	0.363

Table IV-14b
Controlled Harbor Craft Propulsion Engine
Emission Factors (g/bhp-hr)

Horsepower	Tier	NOx	ROG	PM10
25-50	1	6.93	1.30	0.580
	2	5.04	1.30	0.240
	3	5.04	1.30	0.176
51-120	1	6.93	0.71	0.524
	2	5.04	0.71	0.240
	3	5.04	0.71	0.176
121-175	1	8.97	0.49	0.290
	2	4.84	0.49	0.176
	3	3.60	0.49	0.077
176-750	1	8.97	0.49	0.290
	2	4.84	0.49	0.120
	3	3.87	0.49	0.068
751-1900	1	8.97	0.49	0.290
	2	5.24	0.49	0.160
	3	3.87	0.49	0.068
1901 +	1	8.97	0.49	0.290
	2	5.24	0.49	0.160
	3	4.14	0.49	0.085

Table IV-15a
Uncontrolled Harbor Craft Auxiliary Engine
Emission Factors (g/bhp-hr)

Horsepower	Model Year	NOx	ROG	PM10
25-50	all	6.42	1.58	0.460
51-120	pre-1997	12.09	1.23	0.508
	1997+	8.14	0.85	0.417
121-250	pre-1971	13.02	1.13	0.466
	1971-1978	12.09	0.94	0.399
	1979-1983	11.16	0.86	0.333
	1984-1995	10.23	0.82	0.333
	1996+	7.75	0.59	0.255
251-750	pre-1971	13.02	1.08	0.448
	1971-1978	12.09	0.90	0.381
	1979-1983	11.16	0.81	0.321
	1984-1994	10.23	0.77	0.321
	1995+	7.60	0.58	0.230
751 +	pre-1971	13.02	1.08	0.448
	1971-1978	12.09	0.90	0.381
	1979-1986	11.16	0.81	0.321
	1987-1998	10.23	0.72	0.321
	1999+	7.75	0.58	0.255

Table IV-15b
Controlled Harbor Craft Auxiliary Engine
Emission Factors (g/bhp-hr)

Horsepower	Tier	NOx	ROG	PM10
25-50	1	6.54	1.54	0.511
	2	5.04	1.54	0.240
	3	5.04	1.54	0.176
51-120	1	6.93	0.85	0.464
	2	5.04	0.85	0.240
	3	5.04	0.85	0.176
121-175	1	6.93	0.58	0.255
	2	4.84	0.58	0.176
	3	3.60	0.58	0.077
176-750	1	6.93	0.58	0.255
	2	4.84	0.58	0.120
	3	3.78	0.58	0.068
751-1900	1	6.93	0.58	0.255
	2	5.24	0.58	0.160
	3	3.87	0.58	0.068
1901 +	1	6.93	0.58	0.255
	2	5.24	0.58	0.160
	3	4.14	0.58	0.085

Table IV-16
Harbor Craft Load Factors

Vessel Type	Propulsion Engine	Auxiliary Engine
Charter Fishing	0.52	0.43
Commercial Fishing	0.27	
Ferry/Excursion	0.42	
Pilot	0.51	
Tow	0.68	
Work	0.45	
Other	0.52	
Barge/Dredge	0.45	0.65
Crew & Supply	0.38	0.32
Tug	0.50	0.31

Table IV-17
Shore Power
Default Emission Rates Grams per kilowatt-hour (g/kWh)

Pollutant	Emission Rate
NOx	13.9
ROG	0.49
PM10 (marine gas oil fuel with 0.11- 0.5 % sulfur content)	0.38
PM10 (marine gas oil fuel with <= 0.10 % sulfur content)	0.25

Table IV-18
Shore Power
Default Power Requirements

Ship Category	Ship Size / Type Default Twenty-foot Equivalent Unit (TEU)	Power Requirement (kW)
Container Vessel	<1,000	1,000
	1,000 – 1,999	1,300
	2,000 – 2,999	1,600
	3,000 – 3,999	1,900
	4,000 – 4,999	2,200
	5,000 – 5,999	2,300
	6,000 – 6,999	2,500
	7,000 – 7,999	2,900
	8,000 – 9,999	3,300
	10,000 – 12,000	3,700
Passenger Vessel	No Default Value – Use Actual Power Requirement[a]	
Reefer	Break Bulk	1,300
	Fully containerized	3,300

a - The average power requirement for passenger vessels is 7,400 kW (ARB Oceangoing Vessel Survey, 2005).

ALL ENGINES

Table IV-19
Fuel Consumption Rate Factors (bhp-hr/gal)

Category	Horsepower/Application	Fuel Consumption Rate
Non-Mobile Agricultural Engines	ALL	17.5
Locomotive	Line Haul and Passenger (Class I/II)	20.8
	Line Haul and Passenger (Class III)	18.2
	Switcher	15.2
Other	< 750 hp	18.5
	≥ 750 hp	20.8

V. EXAMPLE CALCULATIONS

Example calculations are provided to illustrate all the permutations that staff expects may be included in an application for funding. Example calculations are included for five scenarios providing the values that are needed for a complete application. Those required values are:

- GHG annual emission reductions from each proposed vehicle or piece of equipment;
- Criteria pollutant and toxic air contaminant annual pollutant emission reductions for each proposed vehicle or piece of equipment;
- GHG reduction cost-effectiveness for a two-year life during the time of the proposed project field demonstration;
- GHG reduction cost-effectiveness for a 10-year life, two years after the end of the proposed demonstration project, assuming the technology is commercialized and integrated into the marketplace;
- Criteria pollutant and toxic air contaminant reduction cost-effectiveness for a two-year life during the time of the proposed project field demonstration; and
- Criteria pollutant and toxic air contaminant reduction cost-effectiveness for a 10-year life, two years after the end of the proposed demonstration project, assuming the technology is commercialized and integrated into the marketplace.

GHG emission reductions are calculated on a well-to-wheel basis and the criteria pollutant emission reductions are determined under a tank-to-wheel scenario. The example calculations contained in this appendix are illustrations of:

Battery-Electric Heavy-Lift Forklift

- This example assumes that a heavy-lift forklift will have the same energy requirements as a diesel counterpart and will be used the same number of hours. Electricity to charge the proposed forklift will come from the electrical grid.

Fuel Cell Top Handler

- This example assumes that a fuel cell top handler will have the same energy requirements as a diesel counterpart and will be used the same number of hours. It is assumed that this project will use hydrogen that is SB 1505 compliant and therefore, has a 1/3 renewable component.

Battery-Electric Switch Locomotive with Fuel Cell Range Extender

- This example assumes that a fuel cell switcher locomotive with battery storage will have the same energy requirements as a diesel-electric counterpart and will be used the same number of hours. Further, it is assumed that in this project, continuous power is provided by the fuel cell and peak power requirements are provided by the on-board traction battery. It is assumed that half of the advanced technology vehicle’s energy needs will come from the on-board battery pack and that half of the vehicle’s energy needs will come from the on-board range extending engine.

Hybrid Wheel Loader with Renewable Diesel

- This example assumes that a hybrid wheel loader will have the same energy requirements as a diesel counterpart and will be used the same number of hours. It is assumed that the hybrid system reduces the equipment's fuel consumption by 15% and renewable diesel is used instead of traditional diesel.

Logistic Strategy for Container Movement Technology

- This example assumes that a piece of cargo handling equipment utilizing advanced logistic technology will have the same energy requirements as a diesel counterpart without the logistic technology and will be used the same number of hours. The logistic strategy is only functional while loading and unloading ocean going vessels and therefore, will only be engaged half of the time during the cargo handling equipment's operation.

All of the following examples assume diesel fuel usage by the baseline vehicle or equipment as a basis for the GHG and criteria pollutant emission calculations. This technique may not adequately capture the emission profiles of all proposed applications; however; this technique is used to allow all submitted applications to be scored objectively.

If a proposed project is for an application that uses a baseline diesel engine of 24 hp or lower, for the purpose of this solicitation and to calculate the needed emission reductions and cost-effectiveness, use the relevant tables for a 25 hp baseline diesel engine in the Moyer Guidelines.

Example A: Battery-Electric Heavy-Lift Forklift

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a heavy-lift forklift will have the same energy requirements as a diesel counterpart and will be used the same number of hours. Electricity to charge the proposed forklift will come from the electrical grid.

Baseline Diesel Forklift:

- Off-Road diesel engine: Tier 4 Final certification, 110 hp
- 19,000 lbs. lift capacity
- Diesel usage: 2 gallons per hour, 3,000 gallons per year
- Operation: 1,500 hours per year
- Forklift cost at demonstration: $40,000
- Forklift cost two years after demonstration: $40,000

Advanced Technology:

- Battery-electric forklift
- Forklift cost at demonstration: $75,000
- Forklift cost two years after demonstration: $65,000

Variables Used in Calculation:

Carbon Intensity

From Table II-2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.01\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

$CI_{electricity} = \frac{105.16\ g\ CO2e}{MJ}$ Table Pathway Identifier ELC001

Energy Density

From Table II-1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{electricity} = \frac{3.60\ MJ}{kWh}$

Energy Efficiency Ratio

From Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

$EER_{electricity}$ = 3.8

Step 1: Convert the diesel used per year to the amount of electricity needed to do the same work using Formula 3 and the variables identified above.

Formula 3:

$$Replacement\ Fuel\ Usage\left(\frac{unit}{year}\right) = fuel\ usage * ED_{diesel} * \left(\frac{1}{ED_{replacement\ fuel}}\right) * \left(\frac{1}{EER}\right)$$

Where:

- **ED** is the fuel energy density (see Table II-1: Fuel Energy Density);
- **EER** is the Energy Economy Ratio value for fuels relative to diesel (see Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications);
- **Unit** is the units associated with the replacement fuel. Electricity is in terms of kWh, hydrogen is in kg, and CNG is in scf.

$$Replacement\ Fuel\ Usage\left(\frac{unit}{year}\right) = \left(3{,}000\,\frac{gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{1\ gal\ diesel}\right) * \left(\frac{1\ kWh}{3.60\ MJ}\right) * \left(\frac{1}{3.8}\right)$$
$$= 29{,}500\,\frac{kWh}{year}$$

Step 2: Determine the GHG emissions that are attributed to the baseline diesel-fueled heavy-lift forklift using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$
$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right)$$
$$* \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{base} = \left(\frac{102.01\ gram\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{3{,}000\ gal\ diesel}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 41\,\frac{metric\ tons\ CO2e}{year}$$

Step 3: Determine the GHG emissions that are attributed to the advanced technology forklift using Formula 1, the result from Step 1 and the variables identified above.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right) * \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{ATV} = \left(\frac{105.16\ gram\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{29{,}500\ kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 11\,\frac{metric\ tons\ CO2e}{year}$$

Step 4: Determine the GHG emission reductions that are associated with the proposed project using Formula 4, populated by results from Step 2 and Step 3 above to give the GHG emission benefit from the proposed project.

Formula 4:

$$Project\ GHG\ ER_{annual}\left(\frac{metric\ tons\ CO2e}{year}\right) = GHG\ EF_{base} - GHG\ EF_{ATV}$$

Where:

- **GHG ER$_{\textbf{annual}}$** is the annual GHG emission reductions that are associated with the proposed project;
- **GHG EF$_{\textbf{base}}$** is the GHG emission factor associated with the base case vehicle or equipment that the advanced technology vehicle or equipment is compared against; and
- **GHG ER$_{\textbf{ATV}}$** is the GHG emission factor that is associated with the proposed advanced technology vehicle.

$$Project\ GHG\ ER_{annual} = \left(41\,\frac{metric\ tons\ CO2e}{year}\right) - \left(11\,\frac{metric\ tons\ CO2e}{year}\right)$$

$$= 30 \frac{metric\ tons\ CO2e}{year}$$

Step 5: Determine the annual criteria pollutant emission reductions that are associated with the proposed project. The baseline diesel-fueled forklift is using a 110 hp diesel engine that is certified to the Tier 4 Final emissions standard, therefore, using emission values from Table IV-7 and fuel consumption rate factors from Table IV-19, the result of Step 1 above to populate Formula 13. The forklift will be used 100% of the time in California. There are no criteria pollutant emissions associated with the use of the battery-electric forklift in a tank-to-wheel analysis.

For a Tier 4 Final off-road engine at 110 hp, Table IV-7 gives criteria pollutant emissions per bhp-hr and Table IV-5 gives the load factor. Therefore:

NOx = 0.26 $\frac{g\ NOx}{bhp-hr}$; ROG = 0.06 $\frac{g\ ROG}{bhp-hr}$; PM10 = 0.008 $\frac{g\ PM10}{bhp-hr}$

Load Factor$_{\text{industrial forklift}}$ = 0.20

Formula 12:

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * Horsepower * Load Factor * Activity (hrs/yr) * Percent Operation in California * ton/907,200g*

$$Annual\ ER_{NOx} = \left(0.26 \frac{g\ NOx}{bhp-hr}\right) * (110\ hp) * (0.20) * \left(1{,}500 \frac{hours}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.009 \frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(0.06 \frac{g\ NOx}{bhp-hr}\right) * (110\ hp) * (0.20) * \left(1{,}500 \frac{hours}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.002 \frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(0.008 \frac{g\ PM10}{bhp-hr}\right) * (110\ hp) * (0.20) * \left(1{,}500 \frac{hours}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.0003 \frac{tons\ PM10}{year}$$

Step 6: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Use the results from Step 5 above along with the realization that the proposed battery-electric forklift will not produce any criteria pollutant emissions in a tank-to-wheel scenario to populate Formula 11.

Formula 11:

Annual Weighted Surplus Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

$$WER = \left(0.009\ \frac{tons\ NOx}{year}\right) + \left(0.002\frac{tons\ ROG}{year}\right) + \left(20 * 0.0003\frac{tons\ PM}{year}\right)$$

$$= 0.017\ \frac{tons}{year}$$

Step 7: Determine the incremental cost of the proposed technology using Formula 10 and the equipment costs for the baseline diesel-fueled forklift and the battery-electric heavy lift forklift given at the start of this example. Cost-effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline Equipment:

- Forklift cost at Demonstration: $40,000
- Forklift cost two years after demonstration: $40,000

Advanced Technology:

- Forklift cost at demonstration: $75,000
- Forklift cost two years after demonstration: $65,000

Formula 10:

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Technology ($)

Incremental Cost$_{2\ years}$ = $75,000 – $40,000 = $35,000

Incremental Cost$_{10\ years}$ = $65,000 – $40,000 = $25,000

Step 8: Determine the GHG emission reduction cost-effectiveness for the proposed project using Formula 5 and the results from Step 4 and Step 7.

Formula 5:

$$GHG\ Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton\ CO2e}\right) = \frac{CRF * incremental\ cost}{Project\ GHG\ ER_{annual}}$$

Where, for the purposes of this Solicitation:

- **CRF** is the Capital Recovery Factor;

- **CRF_2 = 0.515**, per Moyer Table G-3a (2-year life);
- **CRF_{10} = 0.111**, per Moyer Table G-3a (10-year life); and
- **Incremental cost** is the difference between the cost of the baseline vehicle or equipment and the advanced technology vehicle or equipment.

$$GHG\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$35{,}000)}{\left(30\ \frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$601\ per\ metric\ ton\ CO2e\ reduced$$

$$GHG\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$25{,}000)}{\left(30\ \frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$93\ per\ metric\ ton\ CO2e\ reduced$$

Step 9: Determine the criteria pollutant cost-effectiveness for the proposed technology. Use the results from Step 6 and Step 7 to populate Formula 8.

Formula 8:

$$\text{Cost-Effectiveness (\$/ton)} = \frac{\text{Annualized Cost (\$/year)}}{\text{Annual Weighted Surplus Emission Reductions (tons/year)}}$$

$$WER\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$35{,}000)}{\left(0.017\ \frac{tons\ WER}{year}\right)}$$

$$= \$1{,}060{,}000\ per\ ton\ weighted\ criteria\ pollutants\ reduced$$

$$WER\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$25{,}000)}{\left(0.017\ \frac{tons\ WER}{year}\right)}$$

$$= \$163{,}200\ per\ ton\ weighted\ criteria\ pollutants\ reduced$$

Example B: Fuel Cell Top Handler

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a fuel cell top handler will have the same energy requirements as a diesel counterpart and will be used the same number of hours. It is assumed that this project will use hydrogen that is SB 1505 compliant and therefore, has 1/3 renewable component.

Baseline Diesel Top Handler:

- Off-road diesel engine: Tier 4 final certification, 300 hp
- Diesel usage: 7.5 gallons per hour
- Operation: 2,500 hours per year, 18,750 gallons of diesel consumed per year
- Top handler cost at demonstration: $550,000
- Top handler cost two years after demonstration: $550,000

Advanced Technology:

- Hydrogen fuel cell top handler
- Top Handler cost at demonstration: $1,000,000
- Top Handler cost two years after demonstration: $750,000

Variables Used in Calculation:

Carbon Intensity

From Table II-2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.01\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

$CI_{hydrogen} = \frac{88.33\ g\ CO2e}{MJ}$ Table Pathway Identifier HYGN005

Energy Density

From Table II-1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{hydrogen} = \frac{120.00\ MJ}{kg}$

Energy Efficiency Ratio

From Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

$EER_{\text{fuel cell vehicle}}$ = 1.9

Step 1: Convert the diesel used per year to the amount of hydrogen needed to do the same work using Formula 3 and the variables identified above.

Formula 3:

$$Replacement\ Fuel\ Usage\left(\frac{unit}{year}\right) = fuel\ usage * ED_{diesel} * \left(\frac{1}{ED_{replacement\ fuel}}\right) * \left(\frac{1}{EER}\right)$$

Where:

- **ED** is the fuel energy density (see Table II-1: Fuel Energy Density);
- **EER** is the Energy Economy Ratio value for fuels relative to diesel (see Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications);
- **Unit** is the units associated with the replacement fuel. Electricity is in terms of kWh, hydrogen is in kg, and CNG is in scf.

$$Replacement\ Fuel\ Usage\left(\frac{unit}{year}\right) = \left(\frac{18{,}750\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{1\ gal\ diesel}\right) * \left(\frac{1\ kg}{120.00\ MJ}\right) * \left(\frac{1}{1.9}\right)$$

$$= 11{,}058\ \frac{kg\ hydrogen}{year}$$

Step 2: Determine the GHG emissions that are attributed to the baseline diesel-fueled top handler. Using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right)$$

$$* \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{base} = \left(\frac{102.01\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{18{,}750\ gal\ diesel}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 257 \frac{metric\ tons\ CO2e}{year}$$

Step 3: Determine the GHG emissions that are attributed to the advanced technology top handler. Using Formula 1, the result from Step 1 and the variables identified above.

Formula 1:

$$GHG\ EF \left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right) * \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{ATV} = \left(\frac{88.33\ gram\ CO2e}{MJ}\right) * \left(\frac{120.00\ MJ}{kg}\right) * \left(\frac{11{,}058\ kg}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 117 \frac{metric\ tons\ CO2e}{year}$$

Step 4: Determine the GHG emission reductions that are associated with the proposed project. Using Formula 4, populated by results from Step 2 and Step 3 above to give the GHG emission benefit from the proposed project.

Formula 4:

$$Project\ GHG\ ER_{annual} \left(\frac{metric\ tons\ CO2e}{year}\right) = GHG\ EF_{base} - GHG\ EF_{ATV}$$

Where:

- **GHG ER$_{\mathbf{annual}}$** is the annual GHG emission reductions that are associated with the proposed project;
- **GHG EF$_{\mathbf{base}}$** is the GHG emission factor associated with the base case vehicle or equipment that the advanced technology vehicle or equipment is compared against; and
- **GHG ER$_{\mathbf{ATV}}$** is the GHG emission factor that is associated with the proposed advanced technology vehicle.

$$Project\ GHG\ ER_{annual} = \left(257 \frac{metric\ tons\ CO2e}{year}\right) - \left(117 \frac{metric\ tons\ CO2e}{year}\right)$$

$$= 140 \frac{metric\ tons\ CO2e}{year}$$

Step 5: Determine the annual criteria pollutant emission reductions that are associated with the proposed project. The baseline diesel-fueled top handler is using a 300 hp diesel engine that is certified to the Tier 4 Final emissions standard, therefore, using emission values from Table IV-7 and off-road load factors from Table IV-5, the result of Step 1 above to populate Formula 12. The top handler will be used 100% of the time in California. There are no criteria pollutant emissions associated with the use of the hydrogen fuel cell top handler in a tank-to-wheel analysis.

For a Tier 4 Final off-road engine at 300 hp, Table IV-7 gives criteria pollutant emissions per bhp-hr and Table IV-5 gives the load factor. Therefore:

NOx = 0.26 $\frac{g\ NOx}{bhp-hr}$; ROG = 0.06 $\frac{g\ ROG}{bhp-hr}$; PM10 = 0.008 $\frac{g\ PM10}{bhp-hr}$

Load Factor$_{\text{container handling equipment}}$ = 0.59

Formula 12:

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * Horsepower * Load Factor * Activity (hrs/yr) * Percent Operation in California * ton/907,200g*

$$Annual\ ER_{NOx} = \left(0.26 \frac{g\ NOx}{bhp-hr}\right) * (300\ hp) * (0.59) * \left(2{,}500 \frac{hours}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.127 \frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(0.06 \frac{g\ NOx}{bhp-hr}\right) * (300\ hp) * (0.59) * \left(2{,}500 \frac{hours}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.029 \frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(\frac{0.008\ g\ PM10}{bhp-hr}\right) * (300\ hp) * (0.59) * \left(2{,}500 \frac{hours}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.004 \frac{tons\ PM10}{year}$$

Step 6: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Using the results from Step 5 above along with the realization that the proposed battery-electric forklift will not produce any criteria pollutant emissions in a tank-to-wheel scenario, populate Formula 11.

Formula 11:

Annual Weighted Surplus Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

$$WER = \left(0.127\ \frac{tons\ NOx}{year}\right) + \left(0.029\frac{tons\ ROG}{year}\right) + \left(20 * 0.004\frac{tons\ PM}{year}\right)$$

$$= 0.236\ \frac{tons}{year}$$

Step 7: Determine the incremental cost of the proposed technology using Formula 10 and the equipment costs for the baseline diesel-fueled top handler and the fuel cell top handler given at the start of this example. Cost-effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline Equipment:

- Top handler cost at Demonstration: $550,000
- Top handler cost two years after demonstration: $550,000

Advanced Technology:

- Top handler cost at demonstration: $1,000,000
- Top handler cost two years after demonstration: $750,000

Formula 10:

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Technology ($)

Incremental Cost$_{2\ years}$ = $1,000,000 – $550,000 = $450,000

Incremental Cost$_{10\ years}$ = $750,000 – $550,000 = $200,000

Step 8: Determine the GHG emission reduction cost-effectiveness for the proposed project using Formula 5 and the results from Step 4 and Step 7.

Formula 5:

$$Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton\ CO2e}\right) = \frac{CRF * incremental\ cost}{Project\ GHG\ ER_{annual}}$$

Where, for the purposes of this Solicitation:

- **CRF** is the Capital Recovery Factor;
- **CRF_2 = 0.515**, per Moyer Table G-3a (2-year life);
- **CRF_{10} = 0.111**, per Moyer Table G-3a (10-year life); and
- **Incremental cost** is the difference between the cost of the baseline vehicle or equipment and the advanced technology vehicle or equipment.

$$GHG\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$450{,}000)}{\left(140\ \frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$1{,}655\ per\ metric\ ton\ CO2e\ reduced$$

$$GHG\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$200{,}000)}{\left(140\ \frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$159\ per\ metric\ ton\ CO2e\ reduced$$

Step 9: Determine the criteria pollutant cost-effectiveness for the proposed technology. Use the results from Step 6 and Step 7 to populate Formula 8.

Formula 8:

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year)}}{\textit{Annual Weighted Surplus Emission Reductions (tons/year)}}$$

$$WER\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$450{,}000)}{\left(0.236\ \frac{tons\ WER}{year}\right)}$$

$$= \$982{,}000\ per\ ton\ weighted\ criteria\ pollutants\ reduced$$

$$WER\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$200{,}000)}{\left(0.236\ \frac{tons\ WER}{year}\right)}$$

$$= \$94{,}100\ per\ ton\ weighted\ criteria\ pollutants\ reduced$$

Example C: Battery-Electric Switch Locomotive with Fuel Cell Range Extender

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a fuel cell locomotive with battery storage will have the same energy requirements as a diesel-electric counterpart and will be used the same number of hours. Further, it is assumed that in this project, continuous power is provided by the fuel cell and peak power requirements are provided by the on-board traction battery. It is assumed that half of the advanced technology vehicle's energy needs will come from the on-board battery pack and that half of the vehicle's energy needs will come from the on-board range extending engine. It is assumed that this project will use hydrogen that is SB 1505 compliant and therefore, has 1/3 renewable component.

Baseline Locomotive:

- Off-road diesel engine with electric drivetrain: Tier 4 certification, 1,500 hp
- Diesel usage: 23 gallons per hour
- Operation: 6,000 hours per year, 138,000 gallons per year
- Locomotive cost at demonstration: $1,500,000
- Locomotive cost two years after demonstration: $1,500,000

Advanced Technology:

- Battery-electric locomotive with fuel cell range extender
- Energy requirements during operation: 50% on electricity, 50% on hydrogen
- Locomotive cost at demonstration: $3,500,000
- Locomotive cost two years after demonstration: $2,500,000

Variables Used in Calculation:

Carbon Intensity

From Table II-2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.01\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

$CI_{electricity} = \frac{105.16\ g\ CO2e}{MJ}$ Table Pathway Identifier ELC001

$CI_{hydrogen} = \frac{88.33\ g\ CO2e}{MJ}$ Table Pathway Identifier HYGN005

Energy Density

From Table II-1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{hydrogen} = \frac{120.00\ MJ}{kg}$

$ED_{electricity} = \frac{3.60\ MJ}{kWh}$

Energy Efficiency Ratio

From Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

$EER_{electric\ heavy\ rail} = 4.6$ $EER_{fuel\ cell\ vehicle} = 1.9$

Step 1: Convert the diesel used per year to the amount of electricity and hydrogen needed to do the same work using Formula 3 and the variables identified above.

Formula 3:

$$Replacement\ Fuel\ Usage \left(\frac{unit}{year}\right) = fuel\ usage * ED_{diesel} * \left(\frac{1}{ED_{replacement\ fuel}}\right) * \left(\frac{1}{EER}\right)$$

Where:

- **ED** is the fuel energy density (see Table II-1: Fuel Energy Density);
- **EER** is the Energy Economy Ratio value for fuels relative to diesel (see Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications);
- **Unit** is the units associated with the replacement fuel. Electricity is in terms of kWh, hydrogen is in kg, and CNG is in scf.

$$Replacement\ Fuel\ Usage_{electricity} = \left(\frac{69{,}000\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{1\ gal\ diesel}\right) * \left(\frac{1\ kWh}{3.60\ MJ}\right) * \left(\frac{1}{4.6}\right)$$
$$= 560{,}000\ \frac{kWh}{year}$$

$$Replacement\ Fuel\ Usage_{hydrogen} = \left(\frac{69{,}000\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{1\ gal\ diesel}\right) * \left(\frac{1\ kg}{120.00\ MJ}\right) * \left(\frac{1}{1.9}\right)$$
$$= 40{,}700\ \frac{kg\ hydrogen}{year}$$

Step 2: Determine the GHG emissions that are attributed to the baseline diesel-fueled locomotive using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right)$$

$$* \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{base} = \left(\frac{102.01\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{138{,}000\ gal\ diesel}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 1{,}893\ \frac{metric\ tons\ CO2e}{year}$$

Step 3: Determine the GHG emissions that are attributed to the advanced technology locomotive. Use Formula 1, the result from Step 1, and the variables identified above to calculate the GHG emissions for electricity and hydrogen separately, then add together.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right)$$

$$* \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{electricity} = \left(\frac{105.16\ g\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{560{,}000\ kWh}{year}\right) * \left(\frac{metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 212\frac{metric\ tons\ CO2e}{year}$$

$$GHG\ EF_{hydrogen} = \left(\frac{88.33\ g\ CO2e}{MJ}\right) * \left(\frac{120.00\ MJ}{kg}\right) * \left(\frac{40{,}700\ kg}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 431 \frac{metric\ tons\ CO2e}{year}$$

$$GHG\ EF_{ATV} = \left(212 \frac{metric\ tons\ CO2e}{year}\right) + \left(431 \frac{metric\ tons\ CO2e}{year}\right)$$

$$= 643 \frac{metric\ tons\ CO2e}{year}$$

Step 4: Determine the GHG emission reductions that are associated with the proposed project. Use Formula 4, populated by results from Step 2 and Step 3 above, to give the GHG emission benefit from the proposed project.

Formula 4:

$$Project\ GHG\ ER_{annual} \left(\frac{metric\ tons\ CO2e}{year}\right) = GHG\ EF_{base} - GHG\ EF_{ATV}$$

Where:

- **GHG ER_{annual}** is the annual GHG emission reductions that are associated with the proposed project;
- **GHG EF_{base}** is the GHG emission factor associated with the base case vehicle or equipment that the advanced technology vehicle or equipment is compared against; and
- **GHG ER_{ATV}** is the GHG emission factor that is associated with the proposed advanced technology vehicle.

$$Project\ GHG\ ER_{annual} = \left(1{,}893 \frac{metric\ tons\ CO2e}{year}\right) - \left(643 \frac{metric\ tons\ CO2e}{year}\right)$$

$$= 1{,}250 \frac{metric\ tons\ CO2e}{year}$$

Step 5: Determine the annual criteria pollutant emission reductions that are associated with the proposed project. The baseline locomotive is using a 1,500 hp diesel engine that is certified to the Tier 4 emissions standard, therefore, using emission values from Table IV-12b and fuel consumption rate factors from Table IV-19, the result of Step 1 above to populate Formula 13. The locomotive will be used 100% of the time in California. There are no criteria pollutant emissions associated with the use of the battery-electric locomotive with the fuel cell range extender in a tank-to-wheel analysis.

For a Tier 4 locomotive engine at 1,500 hp, Table IV-12b gives criteria pollutant emissions per bhp-hr and Table IV-19 gives the fuel consumption rate factor. Therefore:

NOx = 1.22 $\frac{g\ NOx}{bhp-hr}$; ROG = 0.15 $\frac{g\ ROG}{bhp-hr}$; PM10 = 0.026 $\frac{g\ PM10}{bhp-hr}$

Formula 13:

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

$$Annual\ ER_{NOx} = \left(1.22\frac{g\ NOx}{bhp-hr}\right) * \left(15.2\frac{bhp-hr}{gal\ diesel}\right) * \left(138{,}000\frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 2.821\frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(0.15\frac{g\ ROG}{bhp-hr}\right) * \left(15.2\frac{bhp-hr}{gal\ diesel}\right) * \left(138{,}000\frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.347\frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(0.026\frac{g\ PM10}{bhp-hr}\right) * \left(15.2\frac{bhp-hr}{gal\ diesel}\right) * \left(138{,}000\frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.060\frac{tons\ PM10}{year}$$

Step 6: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Use the results from Step 5 above, along with the realization that the proposed battery-electric locomotive with a fuel cell range extender will not produce any criteria pollutant emissions in a tank-to-wheel scenario, to populate Formula 11.

Formula 11:

Annual Weighted Surplus Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

$$WER = \left(2.821\ \frac{tons\ NOx}{year}\right) + \left(0.347\frac{tons\ ROG}{year}\right) + \left(20 * 0.060\frac{tons\ PM}{year}\right)$$

$$= 4.368 \, \frac{tons}{year}$$

Step 7: Determine the incremental cost of the proposed technology using Formula 10 and the equipment costs for the baseline locomotive and the battery-electric locomotive with a fuel cell range extender given at the start of this example. Cost-effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline Equipment:

- Locomotive cost at Demonstration: $1,500,000
- Locomotive cost two years after demonstration: $1,500,000

Advanced Technology:

- Locomotive cost at demonstration: $3,500,000
- Locomotive cost two years after demonstration: $2,500,000

Formula 10:

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Technology ($)

Incremental $\text{Cost}_{2\ \text{years}}$ = $3,500,000 – $1,500,000 = $2,000,000

Incremental $\text{Cost}_{10\ \text{years}}$ = $2,500,000 – $1,500,000 = $1,000,000

Step 8: Determine the GHG emission reduction cost-effectiveness for the proposed project using Formula 5 and the results from Step 4 and Step 7.

Formula 5:

$$Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton\ CO2e}\right) = \frac{CRF * incremental\ cost}{Project\ GHG\ ER_{annual}}$$

Where, for the purposes of this Solicitation:

- **CRF** is the Capital Recovery Factor;
- **CRF_2 = 0.515**, per Moyer Table G-3a (2-year life);
- **CRF_{10} = 0.111**, per Moyer Table G-3a (10-year life); and
- **Incremental cost** is the difference between the cost of the baseline vehicle or equipment and the advanced technology vehicle or equipment.

$$GHG\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$2{,}000{,}000)}{\left(1{,}250\,\frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$824\ per\ metric\ ton\ CO2e\ reduced$$

$$GHG\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$1{,}000{,}000)}{\left(1{,}250\ \frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$89\ per\ metric\ ton\ CO2e\ reduced$$

Step 9: Determine the criteria pollutant cost-effectiveness for the proposed technology. Use the results from Step 6 and Step 7 to populate Formula 8.

Formula 8:

$$\text{Cost-Effectiveness (\$/ton)} = \frac{\text{Annualized Cost (\$/year)}}{\text{Annual Weighted Surplus Emission Reductions (tons/year)}}$$

$$WER\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$2{,}000{,}000)}{\left(4.368\ \frac{tons\ WER}{year}\right)}$$

$$= \$236{,}000\ per\ ton\ weighted\ criteria\ pollutants\ reduced$$

$$WER\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$1{,}000{,}000)}{\left(4.368\ \frac{tons\ WER}{year}\right)}$$

$$= \$25{,}400\ per\ ton\ weighted\ criteria\ pollutants\ reduced$$

Example D: Hybrid Wheel Loader with Renewable Diesel

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a hybrid wheel loader will have the same energy requirements as a diesel counterpart and will be used the same number of hours. It is assumed that the hybrid system reduces the equipment's fuel consumption by 15% and renewable diesel is used instead of traditional diesel.

Baseline Diesel Wheel Loader:

- Off-road diesel engine: Tier 4 final certification, 500 hp
- Diesel usage: 8 gallons per hour
- Operation: 1,500 hours per year, 12,000 gallons of diesel consumed per year
- Wheel Loader cost at demonstration: $800,000
- Wheel Loader cost two years after demonstration: $800,000

Advanced Technology:

- Hybrid wheel loader (Tier 4 final engine) with renewable diesel
- Renewable diesel usage: 6.8 gallons per hour
- Wheel Loader cost at demonstration: $1,400,000
- Wheel Loader cost two years after demonstration: $1,000,000

Variables Used in Calculation:

Carbon Intensity

From Table II-2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.01\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

$CI_{renewable\ diesel} = \frac{102.01\ g\ CO2e}{MJ}$ Table Pathway Identifier RNWD302T

Energy Density

From Table II-1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{renewable\ diesel} = \frac{129.65\ MJ}{gal\ RD}$

Energy Efficiency Ratio

From Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

EER_{diesel} = 1.0

Step 1: Calculate the amount of conventional diesel needed to operate the advanced technology vehicle. Use Formula 7 and the baseline information above.

Formula 7:

$$Fuel\ Usage_{ATV}\left(\frac{gal}{year}\right) = \ fuel\ usage * \left(1 - \frac{(X * Y\%\ improvement)}{100\%}\right)$$

Where:

- **X** is the fraction of the time the advanced operational efficiency technology or logistic strategy is enabled and providing emission reductions. If the advanced operational efficiency technology or logistic strategy is always engaged and providing emission reductions assume that X is equal to 1; and
- **Y** is the percentage fuel economy improvement that is gained by having the advanced operational efficiency technology or logistic strategy efficiency improvement over the baseline engine.

$$Fuel\ Usage_{ATV}\left(\frac{gal}{year}\right) = \left(\frac{12{,}000\ gal\ diesel}{year}\right) * \left(1 - \frac{(1 * 15\%\ improvement)}{100\%}\right)$$

$$= 10{,}200\,\frac{gal\ diesel}{year}$$

Step 2: Convert the diesel used per year to the amount of renewable diesel needed to do the same work. Use Formula 3 and the variables identified above.

Formula 3:

$$Replacement\ Fuel\ Usage\left(\frac{unit}{year}\right) = fuel\ usage * ED_{diesel} * \left(\frac{1}{ED_{replacement\ fuel}}\right) * \left(\frac{1}{EER}\right)$$

Where:

- **ED** is the fuel energy density (see Table II-1: Fuel Energy Density);
- **EER** is the Energy Economy Ratio value for fuels relative to diesel (see Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications);

- **Unit** is the units associated with the replacement fuel. Electricity is in terms of kWh, hydrogen is in kg, and CNG is in scf.

$$Replacement\ Fuel\ Usage = \left(\frac{10{,}200\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{1\ gal\ diesel}\right) * \left(\frac{1\ gal\ RD}{129.65\ MJ}\right) * \left(\frac{1}{1.0}\right)$$

$$= 10{,}580\ \frac{gal\ renewable\ diesel}{year}$$

Step 3: Determine the GHG emissions that are attributed to the baseline diesel-fueled wheel loader using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right)$$

$$* \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{base} = \left(\frac{102.01\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{12{,}000\ gal\ diesel}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 165\,\frac{metric\ tons\ CO2e}{year}$$

Step 4: Determine the GHG emissions that are attributed to the advanced technology wheel loader using Formula 1, the result from Step 1 and the variables identified above.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right)$$

$$* \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{ATV} = \left(\frac{102.01\ g\ CO2e}{MJ}\right) * \left(\frac{129.65\ MJ}{gal\ RD}\right) * \left(\frac{10{,}580\ gal\ RD}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 140 \frac{metric\ tons\ CO2e}{year}$$

Step 5: Determine the GHG emission reductions that are associated with the proposed project. Using Formula 4, populated by results from Step 3 and Step 4 above to give the GHG emission benefit from the proposed project.

Formula 4:

$$Project\ GHG\ ER_{annual} \left(\frac{metric\ tons\ CO2e}{year}\right) = GHG\ EF_{base} - GHG\ EF_{ATV}$$

Where:

- **GHG ER_{annual}** is the annual GHG emission reductions that are associated with the proposed project;
- **GHG EF_{base}** is the GHG emission factor associated with the base case vehicle or equipment that the advanced technology vehicle or equipment is compared against; and
- **GHG ER_{ATV}** is the GHG emission factor that is associated with the proposed advanced technology vehicle.

$$Project\ GHG\ ER_{annual} = \left(165 \frac{metric\ tons\ CO2e}{year}\right) - \left(140 \frac{metric\ tons\ CO2e}{year}\right)$$

$$= 25 \frac{metric\ tons\ CO2e}{year}$$

Step 6: Determine the annual criteria pollutant emissions that are associated with the baseline wheel loader. The baseline wheel loader is using a 500 hp diesel engine that is certified to the Tier 4 Final emissions standard, therefore, using emission values from Table IV-7 and fuel consumption rate factors from Table IV-19, the result of Step 1 above to populate Formula 12. The wheel loader will be used 100% of the time in California.

For a Tier 4 Final off-road engine at 500 hp, Table IV-7 gives criteria pollutant emissions per bhp-hr and Table-24 gives the fuel consumption rate factors. Therefore:

NOx = 0.26 $\frac{g\ NOx}{bhp-hr}$; ROG = 0.06 $\frac{g\ ROG}{bhp-hr}$; PM10 = 0.008 $\frac{g\ PM10}{bhp-hr}$

Formula 13:

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

$$Annual\ ER_{NOx} = \left(0.26\frac{g\ NOx}{bhp{-}hr}\right) * \left(18.5\frac{bhp{-}hr}{gal\ diesel}\right) * \left(12{,}000\frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.064\frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(0.06\frac{g\ ROG}{bhp{-}hr}\right) * \left(18.5\frac{bhp{-}hr}{gal\ diesel}\right) * \left(12{,}000\frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.015\frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(0.008\frac{g\ PM10}{bhp{-}hr}\right) * \left(18.5\frac{bhp{-}hr}{gal\ diesel}\right) * \left(12{,}000\frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.002\frac{tons\ PM10}{year}$$

Step 7: Determine the annual criteria pollutant emissions that are associated with the hybrid wheel loader. The hybrid wheel loader is using a 500 hp diesel engine that is certified to the Tier 4 Final emissions standard, therefore, using emission values from Table IV-7 and fuel consumption rate factors from Table IV-19, the result of Step 2 above to populate Formula 12. The wheel loader will be used 100% of the time in California.

Formula 13:

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

$$Annual\ ER_{NOx} = \left(0.26\frac{g\ NOx}{bhp{-}hr}\right) * \left(18.5\frac{bhp{-}hr}{gal}\right) * \left(10{,}580\frac{gal\ RD}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.056\frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(0.06 \frac{g\ ROG}{bhp-hr}\right) * \left(18.5 \frac{bhp-hr}{gal}\right) * \left(10{,}580 \frac{gal\ RD}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.013 \frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(0.008 \frac{g\ PM10}{bhp-hr}\right) * \left(18.5 \frac{bhp-hr}{gal}\right) * \left(10{,}580 \frac{gal\ RD}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.002 \frac{tons\ PM10}{year}$$

Step 8: Determine the weighted annual emissions reductions that are associated with the proposed project. Using the results from Step 6 and Step 7 above, populate Formula 11.

Formula 11:

Annual Weighted Surplus Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

$$WER = \left(0.064 - 0.056 \frac{tons\ NOx}{year}\right) + \left(0.015 - 0.013 \frac{tons\ ROG}{year}\right) + \left(20 * (0.002 - 0.002) \frac{tons\ PM}{year}\right)$$

$$= 0.010\ \frac{tons}{year}$$

Step 9: Determine the incremental cost of the proposed technology using Formula 10 and the equipment costs for the baseline wheel loader and the hybrid wheel loader given at the start of this example. Cost-effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline Equipment:

- Wheel loader cost at Demonstration: $800,000
- Wheel loader cost two years after demonstration: $800,000

Advanced Technology:

- Wheel loader cost at demonstration: $1,400,000
- Wheel loader cost two years after demonstration: $1,000,000

Formula 10:

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Technology ($)

Incremental Cost$_{\text{2 years}}$ = $1,400,000 – $800,000 = $600,000

Incremental $\text{Cost}_{10\text{ years}}$ = $1,000,000 – $800,000 = $200,000

Step 10: Determine the GHG emission reduction cost-effectiveness for the proposed project using Formula 5 and the results from Step 5 and Step 9.

Formula 5:

$$Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton\ CO2e}\right) = \frac{CRF * incremental\ cost}{Project\ GHG\ ER_{annual}}$$

Where, for the purposes of this Solicitation:

- **CRF** is the Capital Recovery Factor;
- **CRF_2 = 0.515**, per Moyer Table G-3a (2-year life);
- **CRF_{10} = 0.111**, per Moyer Table G-3a (10-year life); and
  Incremental cost is the difference between the cost of the baseline vehicle or equipment and the advanced technology vehicle or equipment.

$$GHG\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$600{,}000)}{\left(25\ \frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$12{,}360\ per\ metric\ ton\ CO2e\ reduced$$

$$GHG\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$200{,}000)}{\left(25\ \frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$888\ per\ metric\ ton\ CO2e\ reduced$$

Step 11: Determine the criteria pollutant cost-effectiveness for the proposed technology. Use the results from Step 8 and Step 9 to populate Formula 8.

Formula 8:

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year)}}{\textit{Annual Weighted Surplus Emission Reductions (tons/year)}}$$

$$WER\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$600{,}000)}{\left(0.010\ \frac{tons\ WER}{year}\right)}$$

$$= \$30{,}900{,}000\ per\ ton\ weighted\ criteria\ pollutants\ reduced$$

$$WER\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$200{,}000)}{\left(0.010\ \frac{tons\ WER}{year}\right)}$$

$$= \$2{,}220{,}000\ per\ ton\ weighted\ criteria\ pollutants\ reduced$$

Example E: Logistic Strategy for Container Movement Technology

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a piece of cargo handling equipment utilizing advanced logistic technology will have the same energy requirements as a diesel counterpart without the logistic technology and will be used the same number of hours. The logistic strategy is only functional while loading and unloading ocean going vessels and, therefore, will only be engaged half of the time during the cargo handling equipment's operation.

Baseline Vehicle:

- Top handler with off-road diesel engine: Tier 4 final certification, 300 hp
- Diesel usage: 7.5 gallons per hour
- Operation: 2,500 hours per year, 18,750 gallons of diesel consumed per year
- Top handler cost at demonstration: $550,000
- Top handler cost two years after demonstration: $550,000

Advanced Technology:

- Top handler with off-road diesel engine: Tier 4 final certification, 300 hp
- Operation: 2,500 hours per year
  - 50% of operation is loading and unloading ocean going vessels
- Logistic system provides a 5% increase in fuel economy while loading and unloading ocean going vessels
- Top handler with logistic technology cost at demonstration: $590,000
- Top handler with logistic technology two years after demonstration: $575,000

Variables Used in Calculation:

Carbon Intensity

From Table II-2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.01\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

Energy Density

From Table II-1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$

Energy Efficiency Ratio

From Table II-3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

$EER_{diesel} = 1.0$

Step 1: Calculate the amount of diesel needed to operate the advanced technology vehicle. Use Formula 7 and the baseline information above.

Formula 7:

$$Fuel\ Usage_{ATV}\left(\frac{gal}{year}\right) = \ fuel\ usage * \left(1 - \frac{(X * Y\%\ improvement)}{100\%}\right)$$

Where:

- **X** is the fraction of the time the advanced operational efficiency technology or logistic strategy is enabled and providing emission reductions. If the advanced operational efficiency technology or logistic strategy is always engaged and providing emission reductions assume that X is equal to 1; and
- **Y** is the percentage fuel economy improvement that is gained by having the advanced operational efficiency technology or logistic strategy efficiency improvement over the baseline engine.

$$Fuel\ Usage_{ATV}\left(\frac{gal}{year}\right) = \left(\frac{18{,}750\ gal\ diesel}{year}\right) * \left(1 - \frac{(0.5 * 5\%\ improvement)}{100\%}\right)$$

$$= 18{,}280\,\frac{gal\ diesel}{year}$$

Step 2: Determine the GHG emissions that are attributed to the baseline vehicle using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right) * \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{base} = \left(\frac{102.01\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{18{,}750\ gal\ diesel}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 257\frac{metric\ tons\ CO2e}{year}$$

Step 3: Determine the GHG emissions that are attributed to the advanced technology vehicle using Formula 1, the result from Step 1 and the variables identified above.

Formula 1:

$$GHG\ EF\left(\frac{metric\ tons\ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{MJ}{gal}\ or\ \frac{MJ}{kg}\ or\ \frac{MJ}{scf}\ or\ \frac{MJ}{kWh}\right) * \left(\frac{gal}{year}\ or\ \frac{kg}{year}\ or\ \frac{scf}{year}\ or\ \frac{kWh}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$GHG\ EF_{ATV} = \left(\frac{102.01\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{18{,}280\ gal\ diesel}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 251\frac{metric\ tons\ CO2e}{year}$$

Step 4: Determine the GHG emission reductions that are associated with the proposed project. Use Formula 4, populated by results from Step 3 and Step 4 above, to give the GHG emission benefit from the proposed project.

Formula 4:

$$Project\ GHG\ ER_{annual}\left(\frac{metric\ tons\ CO2e}{year}\right) = GHG\ EF_{base} - GHG\ EF_{ATV}$$

Where:

- **GHG ER$_{\textbf{annual}}$** is the annual GHG emission reductions that are associated with the proposed project;

- **GHG EF$_{base}$** is the GHG emission factor associated with the base case vehicle or equipment that the advanced technology vehicle or equipment is compared against; and
- **GHG ER$_{ATV}$** is the GHG emission factor that is associated with the proposed advanced technology vehicle.

$$Project\ GHG\ ER_{annual} = \left(257 \frac{metric\ tons\ CO2e}{year}\right) - \left(251 \frac{metric\ tons\ CO2e}{year}\right)$$

$$= 6 \frac{metric\ tons\ CO2e}{year}$$

Step 5: Determine the annual criteria pollutant emissions that are associated with the baseline vehicle. The baseline vehicle is using a 300 hp diesel engine that is certified to the Tier 4 Final emissions standard, therefore, using emission values from Table IV-7 and fuel consumption rate factors from Table IV-19, populate Formula 13. The vehicle will be used 100% of the time in California.

For a Tier 4 Final off-road engine at 300 hp, Table IV-7 gives criteria pollutant emissions per bhp-hr and Table-24 gives the fuel consumption rate factors. Therefore:

NOx = 0.26 $\frac{g\ NOx}{bhp-hr}$; ROG = 0.06 $\frac{g\ ROG}{bhp-hr}$; PM10 = 0.008 $\frac{g\ PM10}{bhp-hr}$

Formula 13:

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

$$Annual\ ER_{NOx} = \left(0.26 \frac{g\ NOx}{bhp-hr}\right) * \left(18.5 \frac{bhp-hr}{gal\ diesel}\right) * \left(18{,}750 \frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.099 \frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(0.06 \frac{g\ ROG}{bhp-hr}\right) * \left(18.5 \frac{bhp-hr}{gal\ diesel}\right) * \left(18{,}750 \frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.023 \frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(0.008 \frac{g\ PM10}{bhp-hr}\right) * \left(18.5 \frac{bhp-hr}{gal\ diesel}\right) * \left(18{,}750 \frac{gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.003 \frac{tons\ PM10}{year}$$

Step 6: Determine the annual criteria pollutant emissions that are associated with the advanced technology vehicle. The vehicle is using a 300 hp diesel engine that is certified to the Tier 4 Final emissions standard, therefore, using emission values from Table IV-7, fuel consumption rate factors from Table IV-19, and the result of Step 2 above to populate Formula 13. The vehicle will be used 100% of the time in California.

Formula 13:

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

$$Annual\ ER_{NOx} = \left(0.26 \frac{g\ NOx}{bhp{-}hr}\right) * \left(18.5 \frac{bhp{-}hr}{gal}\right) * \left(18{,}280 \frac{gal}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.097 \frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(0.06 \frac{g\ ROG}{bhp{-}hr}\right) * \left(18.5 \frac{bhp{-}hr}{gal}\right) * \left(18{,}280 \frac{gal}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.022 \frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(0.008 \frac{g\ PM10}{bhp{-}hr}\right) * \left(18.5 \frac{bhp{-}hr}{gal}\right) * \left(18{,}280 \frac{gal}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ grams}\right)$$

$$= 0.003 \frac{tons\ PM10}{year}$$

Step 7: Determine the weighted annual emissions reductions that are associated with the proposed project. Using the results from Step 5 and Step 6 above, populate Formula 11.

Formula 11:

Annual Weighted Surplus Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

$$WER = \left(0.099 - 0.097\frac{tons\ NOx}{year}\right) + \left(0.023 - 0.022\frac{tons\ ROG}{year}\right) + \left(20 * (0.003 - 0.003)\frac{tons\ PM}{year}\right)$$

$$= 0.003\ \frac{tons}{year}$$

Step 8: Determine the incremental cost of the proposed technology using Formula 10 and the equipment costs for the baseline and advanced technology vehicle given at the start of this example. Cost-effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline Equipment:

- Top handler cost at demonstration: $550,000
- Top handler cost two years after demonstration: $550,000

Advanced Technology:

- Top handler with logistic technology cost at demonstration: $590,000
- Top handler with logistic technology two years after demonstration: $575,000

Formula 10:

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Technology ($)

Incremental Cost$_{2\ years}$ = $590,000 – $550,000 = $40,000

Incremental Cost$_{10\ years}$ = $575,000 – $550,000 = $25,000

Step 9: Determine the GHG emission reduction cost-effectiveness for the proposed project using Formula 5 and the results from Step 4 and Step 8.

Formula 5:

$$Cost\ Effectiveness\ \left(\frac{\$}{metric\ ton\ CO2e}\right) = \frac{CRF * incremental\ cost}{Project\ GHG\ ER_{annual}}$$

Where, for the purposes of this Solicitation:

- **CRF** is the Capital Recovery Factor;
- **CRF_2 = 0.515**, per Moyer Table G-3a (2-year life);
- **CRF_{10} = 0.111**, per Moyer Table G-3a (10-year life); and
- **Incremental cost** is the difference between the cost of the baseline vehicle or equipment and the advanced technology vehicle or equipment.

$$GHG\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$40{,}000)}{\left(6\frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$3{,}433 \; per\ metric\ ton\ CO2e\ reduced$$

$$GHG\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$25{,}000)}{\left(6\,\frac{metric\ tons\ CO2e}{year}\right)}$$

$$= \$463 \; per\ metric\ ton\ CO2e\ reduced$$

Step 10: Determine the criteria pollutant cost-effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula 8.

Formula 8:

$$\textit{Cost-Effectiveness (\$/ton)} = \frac{\textit{Annualized Cost (\$/year)}}{\textit{Annual Weighted Surplus Emission Reductions (tons/year)}}$$

$$WER\ Cost\ Effectiveness_{2\ years} = \frac{(0.515 * \$40{,}000)}{\left(0.003\ \frac{tons\ WER}{year}\right)}$$

$$= \$6{,}867{,}000 \; per\ ton\ weighted\ criteria\ pollutants\ reduced$$

$$WER\ Cost\ Effectiveness_{10\ years} = \frac{(0.111 * \$25{,}000)}{\left(0.003\ \frac{tons\ WER}{year}\right)}$$

$$= \$925{,}000 \; per\ ton\ weighted\ criteria\ pollutants\ reduced$$